

# Contents

<b>List of Figures</b>	<b>xiii</b>
<b>List of Tables</b>	<b>xvii</b>
<b>List of Program Files</b>	<b>xix</b>
<b>Preface</b>	<b>xxi</b>
<b>1 A Brief Tutorial</b>	<b>1</b>
<b>2 Basics</b>	<b>23</b>
2.1 MATLAB Desktop . . . . .	23
2.2 Interaction and Script Files . . . . .	23
2.3 More Fundamentals . . . . .	25
2.4 Help . . . . .	28
2.5 Variables and the Workspace . . . . .	30
<b>3 Distinctive Features of MATLAB</b>	<b>35</b>
3.1 Automatic Storage Allocation . . . . .	35
3.2 Variable Arguments Lists . . . . .	35
3.3 Complex Arrays and Arithmetic . . . . .	37
<b>4 Arithmetic</b>	<b>39</b>
4.1 IEEE Arithmetic . . . . .	39
4.2 Precedence . . . . .	41
4.3 Mathematical Functions . . . . .	42
4.4 Other Data Types . . . . .	42
<b>5 Matrices</b>	<b>47</b>
5.1 Matrix Generation . . . . .	47
5.2 Subscripting and the Colon Notation . . . . .	54
5.3 Matrix and Array Operations . . . . .	57
5.3.1 Implicit Expansion . . . . .	61
5.4 Empty Matrices . . . . .	63
5.5 Matrix Manipulation . . . . .	64
5.6 Data Analysis . . . . .	66
<b>6 Operators and Flow Control</b>	<b>71</b>
6.1 Relational and Logical Operators . . . . .	71
6.2 Flow Control . . . . .	78

<b>7</b>	<b>Program Files</b>	<b>83</b>
7.1	Scripts and Functions . . . . .	83
7.2	Naming and Editing Program Files . . . . .	90
7.3	Working with Program Files and the MATLAB Path . . . . .	91
7.4	Startup . . . . .	92
7.5	Command/Function Duality . . . . .	93
<b>8</b>	<b>Graphics</b>	<b>97</b>
8.1	Two-Dimensional Graphics . . . . .	97
8.1.1	Basic Plots . . . . .	97
8.1.2	Axes and Annotation . . . . .	102
8.1.3	Multiple Plots in a Figure . . . . .	109
8.2	Three-Dimensional Graphics . . . . .	113
8.3	Specialized Graphs for Displaying Data . . . . .	125
8.4	Saving and Printing Figures . . . . .	129
8.5	On Things Not Treated . . . . .	131
<b>9</b>	<b>Linear Algebra</b>	<b>135</b>
9.1	Matrix Properties . . . . .	135
9.2	Norms and Condition Numbers . . . . .	136
9.3	Linear Equations . . . . .	138
9.3.1	Square System . . . . .	138
9.3.2	Overdetermined System . . . . .	140
9.3.3	Underdetermined System . . . . .	141
9.4	Inverse, Pseudoinverse, and Determinant . . . . .	142
9.5	LU, LDL*, and Cholesky Factorizations . . . . .	143
9.6	QR Factorization . . . . .	145
9.7	Singular Value Decomposition . . . . .	146
9.8	Eigenvalue Problems . . . . .	148
9.8.1	Eigenvalues . . . . .	148
9.8.2	More about Eigenvalue Computations . . . . .	150
9.8.3	Generalized Eigenvalues . . . . .	151
9.9	Iterative Linear Equation and Eigenproblem Solvers . . . . .	153
9.10	Functions of a Matrix . . . . .	156
<b>10</b>	<b>More on Functions</b>	<b>159</b>
10.1	Function Handles . . . . .	159
10.2	Anonymous Functions . . . . .	160
10.3	Local Functions . . . . .	161
10.4	Default Input Arguments . . . . .	163
10.5	Variable Numbers of Arguments . . . . .	165
10.6	Argument Checking and Parsing . . . . .	167
10.7	Nested Functions . . . . .	168
10.8	Private Functions . . . . .	169
10.9	Recursive Functions . . . . .	170
10.10	Global and Persistent Variables . . . . .	173
10.11	Exemplary Functions in MATLAB . . . . .	174

<b>11 Numerical Methods: Part I</b>	<b>175</b>
11.1 Polynomials and Data Fitting . . . . .	175
11.2 Nonlinear Equations . . . . .	180
11.3 Optimization . . . . .	184
11.4 The Fast Fourier Transform . . . . .	185
<b>12 Numerical Methods: Part II</b>	<b>189</b>
12.1 Numerical Integration . . . . .	189
12.2 Ordinary Differential Equations . . . . .	193
12.2.1 Examples with Ode45 . . . . .	193
12.2.2 Case Study: Pursuit Problem with Event Location . . . . .	201
12.2.3 Stiff Problems, Differential-Algebraic Equations, and the Choice of Solver . . . . .	205
12.3 Boundary-Value Problems . . . . .	213
12.4 Delay-Differential Equations . . . . .	221
12.5 Partial Differential Equations . . . . .	225
<b>13 Input and Output</b>	<b>233</b>
13.1 User Input . . . . .	233
13.2 Output to the Screen . . . . .	234
13.3 File Input and Output . . . . .	236
13.4 Fine Tuning the Display of Arrays . . . . .	238
<b>14 Troubleshooting</b>	<b>241</b>
14.1 Errors and Assertions . . . . .	241
14.2 Warnings . . . . .	243
14.3 Debugging . . . . .	245
14.4 Pitfalls . . . . .	246
<b>15 Sparse Matrices</b>	<b>249</b>
15.1 Sparse Matrix Generation . . . . .	249
15.2 Linear Algebra . . . . .	252
<b>16 More on Coding</b>	<b>257</b>
16.1 Elements of Coding Style . . . . .	257
16.2 Cleaning Up . . . . .	258
16.3 Checking and Comparing Code Files . . . . .	259
16.4 Profiling . . . . .	260
16.5 P-Code . . . . .	261
16.6 Source Control . . . . .	264
16.7 Live Editor . . . . .	264
16.8 Creating a Toolbox . . . . .	265
16.9 Distributing Code Files . . . . .	268
16.10 Unit Tests . . . . .	269
<b>17 Advanced Graphics</b>	<b>273</b>
17.1 Objects, Handles, and Properties . . . . .	273
17.2 Root and Default Properties . . . . .	278
17.3 Animation . . . . .	279
17.4 Examples . . . . .	281

<b>18 Other Data Types and Multidimensional Arrays</b>	<b>291</b>
18.1 Character Vectors and Arrays . . . . .	292
18.2 String Arrays . . . . .	295
18.3 Multidimensional Arrays . . . . .	297
18.4 Categorical Arrays . . . . .	299
18.5 Datetime and Duration Arrays . . . . .	300
18.6 Tables and Timetables . . . . .	304
18.7 Structures and Cell Arrays . . . . .	308
<b>19 Object-Oriented Programming</b>	<b>315</b>
19.1 Max-Plus Algebra Class . . . . .	315
19.2 Circulant Matrix Class . . . . .	321
19.3 On Things Not Treated . . . . .	324
<b>20 The Symbolic Math Toolbox</b>	<b>325</b>
20.1 Creating Symbolic Variables and Expressions . . . . .	325
20.2 Equation Solving . . . . .	327
20.3 Calculus . . . . .	330
20.3.1 Integration . . . . .	330
20.3.2 Differentiation . . . . .	332
20.3.3 Solving Differentiation Equations . . . . .	335
20.3.4 Taylor Expansions . . . . .	336
20.4 Linear Algebra . . . . .	337
20.5 Polynomials and Rationals . . . . .	339
20.6 Variable-Precision Arithmetic . . . . .	343
20.7 Other Features . . . . .	347
<b>21 Graphs</b>	<b>349</b>
21.1 Undirected Graphs . . . . .	349
21.2 Directed Graphs . . . . .	351
<b>22 Large Data Sets</b>	<b>361</b>
22.1 Datastores . . . . .	361
22.2 MapReduce . . . . .	364
22.3 Tall Arrays . . . . .	364
<b>23 Optimizing Codes</b>	<b>369</b>
23.1 Timing Code . . . . .	369
23.2 Vectorization . . . . .	370
23.3 Accessing Matrices by Column . . . . .	372
23.4 Preallocating Arrays . . . . .	374
23.5 Miscellaneous Optimizations . . . . .	374
23.6 Illustration: Bifurcation Diagram . . . . .	375
23.7 External Codes . . . . .	375
<b>24 Tricks and Tips</b>	<b>379</b>
24.1 Empty Arrays . . . . .	379
24.2 Exploiting Infinities . . . . .	380
24.3 Permutations . . . . .	380
24.4 Rank-1 Matrices . . . . .	382

24.5	Set Operations . . . . .	383
24.6	Subscripting Matrices as Vectors . . . . .	384
24.7	Avoiding If Statements . . . . .	385
<b>25</b>	<b>The Parallel Computing Toolbox</b>	<b>387</b>
25.1	The Parfor Loop . . . . .	388
25.2	Asynchronous Computing with Parfeval . . . . .	392
25.3	Batch Computations . . . . .	393
25.4	Single Program, Multiple Data . . . . .	395
25.5	Distributed and Codistributed Arrays . . . . .	397
25.6	GPU Computing . . . . .	398
25.7	On Things Not Treated . . . . .	401
<b>26</b>	<b>Case Studies</b>	<b>403</b>
26.1	Introduction . . . . .	403
26.2	Brachistochrone . . . . .	403
26.3	Small-World Networks . . . . .	404
26.4	Performance Profiles . . . . .	409
26.5	Multidimensional Calculus . . . . .	416
26.6	L-Systems and Turtle Graphics . . . . .	420
26.7	Black–Scholes Delta Surface . . . . .	422
26.8	Chutes and Ladders . . . . .	425
26.9	Pythagorean Sum . . . . .	430
26.10	Fisher’s Equation . . . . .	432
<b>A</b>	<b>The Top 111 MATLAB Functions</b>	<b>439</b>
	<b>Glossary</b>	<b>445</b>
	<b>Bibliography</b>	<b>447</b>
	<b>Index</b>	<b>459</b>